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development of remote-sensing based procedure to estimate boulder concentrations

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Abstract:

Existing methods of estimating the percentage of boulders in bouldery soil for contract bidding purposes are inadequate. The object of this study is to investigate the capabilities of remote sensing techniques, both photographic and non-photographic, and to devise a method to increase the accuracy of boulder estimates.

A procedure was developed based on testing of three sites in the Precambrian Shield of Northern Ontario using black and white airphotos in two scale ranges, 1:30 000 - 1:60 000 and 1:10 000 - 1:16 000. By identifying landforms, reconstructing their geographical history and determining the extent of glacial and post-glacial modification subsequent to their formation, concentration estimates can be as close as ±20%. Essential to application of these findings is that the interpreter have a strong background in Pleistocene geology. Application is limited in areas where landforms are poorly developed or where the effects of glacial and post-glacial processes are indistinct.

Key Words: estimate, airphoto, boulder concentration, glacial geology

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DEVELOPMENT OF REMOTE SENSING-BASED PROCEDURE TO ESTIMATE BOULDER CONCENTRATIONS

SP-015

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Prepared for
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Surveys and Plans Office, MTC

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Portions of Surficial Geology Map S 165 (1:506 880; 1965) and Northern Ontario Engineering Geology Terrain Study Map 5073 (1:1 000 000; 1980) are used with permission of the Ontario Ministry of Natural Resources.

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1. INTRODUCTION

1.1 Background

The problem statement prepared by the Ministry is,

"In bouldery soil, accurate boulder content is necessary for soil design and contract bidding. Experience has shown that boulder content could be substantially underestimated, often resulting in large claims by the contractor. Therefore, it is important to be able to estimate boulder contents in cuts more accurately for future projects.

"The present method of estimating boulder contents are based on a variety of limited ground exploration, visual observation and experience. The latter aspect tends to set an empirical limit on one's estimate. Moreover, to obtain reliable results, extensive sampling is required which makes it extremely expensive, particularly in locations where access is difficult.

"Airphotos, acquired when ground cover is at a minimum, can detect, identify and delineate surface boulders and their distribution. At 1:10,000 scale, boulders larger than 1 m in diameter could be visible. At larger scales, smaller boulders can be observed. Figures derived by the Pavement and Foundation Design Section indicate some degree of correlation between the density of surface boulders and boulder content of cuts. However, this correlation may vary with the geographical location and the corresponding geological setting".

1.2 Objectives

The primary objectives of this study involve the investigation of the capabilities of remote sensing techniques for estimating both surface and subsurface boulder concentrations.

An additional objective evolved as the study proceeded. This involved the development of a procedure for estimating boulder concentrations utilizing remote sensing, interpretation of geological processes, and field investigations.

1.3 Scope

Both photographic and non-photographic remote sensing techniques were investigated regarding their possible applications to evaluating boulder concentrations. These evaluations were based on a literature search and a review of existing publications, and previous investigations

carried out by our firm. In addition to the capabilities of the photography and/or imagery to assist in determining boulder concentrations, other factors were considered. These included the availability of the photography/ imagery; cost of acquisition; optimum time of year; and most effective scales.

The study was restricted to the examination of three specific highway locations where moderate to high boulder concentrations were known to exist. Each area consisted of different types and areal extent of surficial geological deposits. The history of glacial and post-glacial processes varied among locations, as did the depths to bedrock of the pleistocene deposits. In each case, field test data compiled by Ministry personnel before and/or after construction were made available.

In addition to data acquired through remote sensing, each test area was examined independently by four persons, with different areas of expertise, from our firm. All were experienced airphoto interpreters, two having a background in civil engineering and two in pleistocene geology.

Field investigations to evaluate the method were limited to six days on the three test areas during November, 1983.

The method of estimating surface and/or subsurface boulder concentrations developed during this study is intended to be of practical use during the pre-contract engineering stage to facilitate preliminary design and cost estimating. The present investigative procedures by Ministry personnel have been incorporated into this method and/or modified where applicable.

The relative levels of accuracy of the method and the variables affecting this are addressed. Also, the limitations of the method are stated.

1.4 Summary of Conclusions and Recommendations

1. According to available literature and publications, this investigation is the first attempt to quantify the concentrations of surface and/or buried boulders in glacial deposits.

2. Black and white panchromatic airphotos are the best remote sensing method, based on resolution of terrain details, availability at appropriate scales, and cost of acquisition.

3. While leaf-free aerial photography is best for delineation of surface boulder deposits, variations in vegetation on these deposits, such as the presence of conifers, reduces the value of leaf-free photography. Therefore, the time of year of acquisition of photography (spring

through fall) is not important.

4. The interpretation of traditional airphoto interpretation pattern elements are useful only for landform identification. Variations in any combination of these elements are not consistently related to surface and/or buried boulder concentrations.

5. The most important factor related to evaluation of surface and/or buried boulder concentrations is the effects on the landforms of glacial and post-glacial processes.

6. Of the three case studies investigated, only the Bending Lake Road had sufficient thickness of overburden and development of landforms, combined with definitive effects of glacial and post-glacial processes to develop a method for estimating surface and/or buried boulder concentrations.

7. The proposed method for determining surface and/or buried boulder concentrations set out herein is, at this point, limited to areas where the glacial deposits, not the bedrock, control the topography and drainage. Therefore, further case studies should recognize this constraint.

8. The recommended procedure for estimating surface, buried or total boulder concentrations should include the following steps, in order.

(a) Acquisition and review of existing geological maps and test data.

(b) Preliminary airphoto interpretation of landforms, surface boulder concentrations and effects of glacial and post glacial processes, using small scale (1:30,000 to 1:60,000) black and white panchromatic airphotos available from government agencies.

(c) Reconnaissance field investigation to confirm landforms, geological processes, and boulder rock types.

(d) Final detailed airphoto interpretation and mapping of data examined in step (b) above for specific areas, using larger scale (1:10,000 to 1:16,000) airphotos available from government agencies.

(e) Final detailed field investigation.

9. The investigation must involve persons having a thorough understanding of pleistocene geology and glacial processes.

10. The use of remote sensing in estimating surface and/or buried boulder concentrations depends mostly upon the capabilities of the interpreter and his/her understanding of pleistocene geology and glacial processes. Poorly developed landforms having shallow overburden and/or lack of glacial and post-glacial processes within a particular area, limit the applications regarding estimates of boulder concentrations under the present state-of-the-art.

2. PROCEDURES AND ANALYSIS

The procedures and subsequent analysis were revised throughout the study. Initially, only remote sensing techniques were to be investigated using the portion of the Bending Lake road constructed prior to October 1982, as the test area. The initial method, devised from examination of existing information and remote sensing, was presented by Glenn Bird of Bird and Hale Ltd. to the M.T.C. Geotechnical Committee on December 8, 1982. As the initial method was restricted to field data from only one test area, it was decided that other test areas should be added to the study to assist in evaluating the method and its limitations. Mr. Ray Girard, Head, Geotechnical Section, Northwestern Region, suggested that the as yet unconstructed portion of the Bending Lake road be included.* Subsequently, a section of Highway 631 near White River and the Dubreuilville Road also were added as test areas.

This section of the report discusses, under the appropriate headings, the procedures undertaken throughout this investigation and the results of the analyses.

2.1 Review of Existing Information

The existing methods of determining boulder concentrations using remote sensing were investigated through literature searches and personal contacts. Previous projects carried out by Bird and Hale Ltd. involving granular material searches throughout Ontario, state-of-the-art reports in the interpretation of physical terrain conditions, detection and evaluation of buried granular deposits, and, recommended remote sensing techniques set out in manuals for soil type identification were examined in relation to this study (see Appendix D for a list of references). The references listed in this report are limited to those directly relating to the test areas examined, as well as those which further explain pertinent remote sensing principles discussed herein.

The present Ministry procedures for estimating surface and/or buried boulder concentrations were examined in detail for the three test areas described in Section 2.5.

Available maps and publications on the three test areas were obtained and evaluated in relation to their applicability for estimating surface and/or buried boulder concentrations. Surficial geology and engineering terrain geology maps for the Bending Lake road were available (see Maps 1 and 2, Appendix A).

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*Subsequent to this meeting but prior to the field investigations, this section of the Bending Lake road was constructed.

A report on the Bending Lake road area, prepared in 1980 by D.G. Mollard and J.D. Mollard, was obtained and examined. Map 2, Appendix A, is the engineering terrain geology map from this report.

Review and analysis of the information outlined above resulted in the following conclusions.

1. Previous methods of determining boulder concentrations as indicated in the publications and by personal contacts, existed only in a qualitative sense. Glacial landforms were described as either containing boulders or not, and where field test holes were not included, reference to boulder sizes and/or density of placement was not made in publications.

   Granular material searches covering specific areas included field test hole data. However, where surface and/or buried granular deposits contained boulders of sufficient size and/or density to constrain or restrict test hole logging using standard equipment, such as backhoes, the area was usually abandoned as granular materials source. Thus, no useful information relating to surface and/or buried boulder concentrations was identified.

   It was concluded that the prediction of boulder concentrations, whether surface or buried, has not been reported upon either in the published literature or specific studies carried out by Bird and Hale Ltd.

2. The present Ministry procedures for estimating surface and/or buried boulder concentrations have understandably varied depending upon specific site conditions. The concentrations of surface boulders can be easily determined through field observations. The main difficulty of estimating buried boulder concentrations involves refusal of the testing equipment on boulders, which often occurs at shallow depths. Information from such tests is very difficult to translate into buried boulder concentrations, as the object causing refusal could be: a small, isolated boulder; one or more large boulders placed loosely or densely; or bedrock. In some cases, several test holes were placed close together in an attempt to evaluate the significance of variable depths of soil penetration to refusal. This statistical approach did not yield further reliable information. Therefore, the estimates of surface and/or buried boulder concentrations using such data have a low level of accuracy. It appears that although the present methods have been applied diligently, the low level of accuracy achieved is not surprising. As a result, the existing method which consists largely of field procedures, had to be augmented with other steps.

3. The surficial and engineering terrain geology maps, as well as their accompanying reports, indicate the landforms and general engineering problems or benefits. The stated purpose of this mapping or inventory is "to assist regional engineering and resource planning studies at a level of detail consistent with a map scale of 1:100,000". Consequently, boulder contents are discussed generally in relation to specific landforms. The mapping, while useful for landform identification, was not intended to represent surface and/or buried boulder concentrations.

2.2 Remote Sensing Methods

Both non-photographic and photographic imagery were evaluated regarding their applications to achieving the study objectives in terms of resolution, relative cost and availability.

The first factor considered in evaluating remote sensing methods was resolution. A high degree of resolution is essential for this study to not only detect surface boulder deposits, but also evaluate the details of landform pattern elements. Resolution is the ability of the entire remote sensing system to render a sharply defined image. Moreover, with all else being equal, resolution is dependent directly upon the flying height. For non-photographic systems, resolution is defined by the dimensions of the smallest area which can be analyzed and imaged by the system. The resolution of non-photographic systems is usually expressed in terms of pixel sizes, a pixel being the smallest area which can be analyzed by the system. For example, the pixel size for Landsat 4 imagery is 57 m by 82 m. For photographic systems, resolution is expressed in terms of lines per millimetre and depends upon the entire photographic system, including lens, film type, exposure, processing, etc., as well as flying height. For example a system having a resolution of 10 lines/mm will permit an object 1 m in size to be resolved at a scale of 1:10,000, using a camera with a standard 153 mm lens. Resolution is discussed in detail in the "Manual of Remote Sensing", Second Edition, published by the American Society of Photogrammetry, 1983.

Cost and availability of non-photographic imagery were also assessed. Acquisition of imageries such as radar and infrared scanning is costly and requires a special mission and operation of high technology equipment. Landsat 4 imagery is available at nominal cost.

In summary, analysis of the above indicates that the low resolution of non-photographic imagery renders it unsuitable for the study objectives. Landsat imagery provides an

overview of the area under investigation and generally is the only non-photographic imagery that is readily available. However, in addition to having low resolution, this imagery cannot be viewed stereoscopically. Therefore, high altitude photography is the logical alternative to provide an overview of the area, since it provides high resolution, can be viewed stereoscopically, and is available at nominal cost.

The photographic remote sensing systems and films considered to assist in achieving the study objectives all provide the required resolution. Three film types and their possible applications, availability, and relative cost of acquisition are discussed: colour, colour infrared, and black and white panchromatic.

Colour photography, because it provides various hues of green, assists in the identification of vegetative species. However, vegetation types, primarily treed growth, in areas of high versus low surface and/or buried boulder concentrations are not consistently different from one another. This conclusion is based on an examination of the vegetation on existing black and white panchromatic airphotos in comparison with areas of known high surface and/or buried boulder concentrations as identified from MTC data. Moreover, colour photography is not always available. Therefore, it would have to be acquired specifically for the areas being investigated. This represents an additional cost factor, as a special flight mission would have to be arranged. In view of the above considerations, colour photography was not considered to be of assistance in this study.

Colour infrared photography is known for its sensitivity to soil moisture and vegetation vigour. Soil moisture conditions may be indicative of surface boulder concentrations, but do not necessarily reflect buried boulder concentrations. For example, outwash areas consisting of sand and gravel appear similar to those areas containing cobbles and boulders with respect to soil moisture conditions. Vegetation vigour, in relation to surface and/or buried boulder concentrations, may show minor variations on colour infrared photography: the only relevant factor, other than soil moisture discussed above, may be a relative lack of nutrients for vegetation from soils having high boulder concentrations. The low nutrient values would occur more commonly in bouldery soils versus finer materials because of the reduced total surface area of the individual soil particles available for retention of nutrients. The net effect may be a reduced vegetation vigour which may be discernable on the colour infrared photography. This may be of some assistance in detecting high boulder concentrations just below the surface. However, the effect of the nutrient level would only indicate soil conditions to the depth of root penetration. Trees that

develop in shallow versus deep soil conditions may be just as vigourous. Furthermore, as with colour photography, the effect of boulder content on species is not consistent, and the hues exhibited on the imagery may not be consistent among various study areas.

The ideal time of year for acquiring infrared colour photography for vegetation vigour analysis is during early spring under the most rapid growth conditions. As this occurs when the leaf cover is partially, but not yet fully developed, ease of delineation of surface boulder deposits is reduced. This partial or minimum leaf cover is therefore undesirable when compared with leaf-free (no leaves, very early spring) photography. The importance of obtaining leaf-free photography is further discussed in Section 2.3.

In summary, infrared colour photography may be of some assistance in determining the relative concentrations of buried boulders. The benefits are unknown at this time. Consequently, further research would be required. This would, in the author's opinion, be economically justified only if additional airphotos, using other film types such as black and white panchromatic, were acquired during the same flight for comparison.

Black and white panchromatic aerial photography is available for the entire province from both the Ontario Ministry of Natural Resources (MNR) and Energy, Mines and Resources Canada. In addition, aerial photography is available from other government agencies, such as the Ontario Ministry of Transportation and Communications. Complete, provincial coverage, though, is not available from these other sources. Coverage available from MNR is taken under full leaf cover, while the federal government photography may be taken at any time from spring to late fall. Thus, federal government photographs may be taken under leaf-free, minimum-leaf, or full-leaf cover, and the density of leaf cover for a particular study area is purely a matter of chance. The scale of provincial photography varies from 1:15,840 (before 1978) to 1:10,000. The federal government coverage varies from 1:10,000 to 1:125,000. Black and white photography is therefore available at a nominal cost from government agencies and at a variety of scales, taken under various leaf cover conditions.

The value of panchromatic airphotos for interpretation of terrain conditions is well established. Consequently, interpretation of black and white panchromatic photography is potentially the most cost effective remote sensing method for evaluating surface and/or buried boulder concentrations. It is readily available at low cost, has high resolution, and has a proven record of reliability for interpretation of physical terrain conditions.

2.3 Interpretation of Remotely Sensed Data

Remote sensing, in this case airphoto interpretation using existing black and white panchromatic airphotos, was used to evaluate the terrain conditions for landform identification and assessment of glacial and post-glacial processes. The photographic scales were either 1:10,000 or 1:15,840 depending upon the availability of MTC or MNR photography for each study area.

The interpretation was initially carried out by analyzing the traditional terrain pattern elements for areas having known boulder concentrations based on Ministry investigations. The available data pertained to the cut sections of the southerly portion of the Bending Lake Road along which construction had been completed prior to December, 1982 (see Map 3, Appendix A). Therefore, the boulder concentrations within each cut section were known. The road location and boulder concentrations were plotted on the existing airphotos, taken prior to construction in 1977, at a scale of 1:15,840 (see Figures 1a and 2a, Appendix B).

The pattern elements examined were topography, drainage, erosion, tone, texture, and vegetation. This was carried out to compare the pattern elements of areas surrounding both low and high total (both surface and buried) boulder concentrations, in the hope that one or more of these elements would differ in relation to the known surface and/or buried boulder concentrations. Surface boulder concentrations visible on the airphotos were mapped simultaneously, in the initial belief that high surface boulder concentrations were indicative of similar buried concentrations. Other than positive identification of landforms, this investigation revealed that:

1. No consistent change in any pattern element could be correlated to surface and/or buried boulder content. Therefore, variations in pattern elements could not be used to estimate boulder content, either surface or buried.

2. Surface boulder deposits, visible through a sparse vegetative cover, could be identified at the photographic scales used. However, no consistent relationship between surface and buried boulder concentrations was found to exist.

The significance of the detection of surface boulder deposits required further discussion. The vegetation is not consistent in an area having surface boulder deposits. It varies from sparse deciduous through mixed to dense coniferous growth. In areas of deciduous vegetation, the detection of surface boulder concentrations is

more easily and accurately carried out using leaf-free photography. Where dense coniferous growth occurs, the time of year of the photography makes no difference as the ground surface is not visible at any time from the air. Therefore, the use of leaf-free photography is of limited value, as some surface boulder deposits will be visible while others will not, especially since mixed and coniferous stands are more prevalent than deciduous stands. This could result in some confusion, as the interpreter would expect to see surface boulder concentrations in a similar setting to that where they are visible, yet he or she would not see them because of the coniferous cover. Also, surface boulder concentrations are easily visible during reconnaissance field checking along the preliminary route and would be identified at that time. Moreover, the conclusion that surface boulder concentrations are not necessarily related to buried boulder concentrations should be borne in mind. This relationship depends primarily upon the glacial and post-glacial processes that have affected the landforms since original deposition.

A photographic scale of between 1:10,000 and 1:15,840 is adequate for the detection of surface boulder deposits (if visible through vegetative cover); accurate identification of landforms; and, recognition of modifications to landforms by glacial and post-glacial processes, which is another requirement for determination of boulder concentration.

In summary, analysis of the results of interpretation of remote sensed data yielded the following conclusions:

1. Pattern elements were of use only for the identification of landforms.

2. The relationship between surface boulder deposits and buried boulder deposits was not consistent.

3. Leaf-free photography is of limited benefit in satisfying the study objectives.

4. Scales of existing photography are suitable for evaluating the required terrain conditions.

5. Evaluation of modifications to landforms by glacial and post-glacial processes is essential to predict both surface and buried boulder concentrations.

2.4 Factors Controlling Boulder Concentrations

As a result of the investigation described in Section 2.3, the factors which control boulder concentration were determined. These are listed below.

1. Landform

Those potentially containing boulders are one or more of the following: terminal moraine, lateral moraine, ridge moraine, kettle-kame moraine, ground moraine, outwash plains, beach ridges, kames, eskers and drumlins.

2. Parent Material

This is the soil which was originally deposited by glacial action. As soil horizons have subsequently formed on the surface, the surface layer of the original parent material has been altered. The buried boulder content within the parent material is related to the hardness of the rock types contained within. For example, if the rock is limestone, the grinding action within the glacier would reduce the particles to smaller sizes than if the rock type was granite. Thus, if all other factors are equal, granite in the parent material would indicate a probability of higher buried boulder concentration.

3. Distance of Glacial Transport

The distance that the glacial material has been transported has a direct effect on both surface and buried boulder concentrations. Materials transported for greater distances have been subjected to more grinding action and are thus more reduced in particle size, resulting in lower surface and/or buried boulder concentrations. The reverse is also true, thus resulting in higher concentrations. An additional aspect relates to the relative distance of glacial deposits from the centre of glaciation. It is generally true that the glacial deposits closest to the centres of glaciation have a higher boulder content. This is illustrated by the marked reduction in particle sizes for most bouldery landforms in Southern Ontario versus those in Northern Ontario.

4. Modifications to Landforms by Glacial and Post-Glacial Processes

Landforms are commonly subjected to additional glacial processes either during or after deposition. This complex process is best illustrated by examples. Consider that the original landform is a bouldery till. If ponding subsequently takes place, the till will be obscured by a layer of lacustrine soils. Alternatively, if the till is "washed" by glacial melt waters, the finer materials will be removed, thus leaving a layer of surface boulders. If the original till deposit is thin, the surface boulders may represent the only remaining evidence of this deposit. Under these circumstances, the deposits underlying the till could be different landforms having either a low or high buried boulder content. The underlying landform may be visible on a nearby eroded slope, thus assisting in its

identification. If the original till deposit is thick, the surface boulders will represent the buried boulder concentration. Therefore, the interpreter would expect to find evidence of the same landform on nearby slopes.

Other examples of interpretation of glacial and post-glacial processes are discussed in Section 2.5.

While all four factors controlling surface and/or buried boulder concentration are important, the modifications to landforms (item 4. above) is the most significant in most situations. It is also the most difficult to interpret, because this work requires knowledge and experience in both airphoto interpretation and pleistocene geology.

In summary, the relative importance of the four factors discussed in this section varies considerably depending upon the location and pleistocene geology of each study area. The wide range of glacial deposits and processes which have influenced the terrain conditions throughout Ontario further complicates the evaluation of these factors.

2.5 Case Studies

Three areas were examined in detail. These are listed below and the location of each is shown on the appropriate map number indicated (see Appendix A).

(a) The Bending Lake Road - Map No. 3

(b) Highway No. 631, White River - Map No. 4

(c) Dubreuilville Road - Map No. 5

These case studies consisted of the following:

i) review of available geological maps and reports.
ii) discussions with persons familiar with the pleistocene geology of the study area.
iii) review of plans, profiles and borehole data of the three road alignments prepared by MTC personnel.
iv) airphoto interpretation and mapping of the pleistocene geology.
v) field investigations.

It should be noted that the primary objective of this study is to develop a method for estimating boulder concentrations. During data review, airphoto interpretation and initial field investigations, it became evident that the Bending Lake study area was the best study area in which to develop this method. The Bending Lake area is the most suitable because the landforms are well developed and have sufficient depth of overburden to reflect their

own characteristics rather than those of the underlying bedrock; and, a variety of glacial and post-glacial modifications have occurred to these landforms. The Dubreuilville Road and Hwy. 631 areas are not as suitable because the landforms are not well developed, consisting of a thin till plain over bedrock interspersed with outwash deposits having a small areal extent; and, glacial and post-glacial modifications to the landforms are not readily apparent either on the airphotos or in the field.

For the above-mentioned reasons, the investigation was concentrated on the Bending Lake Road area, and it was used to develop a method for estimating boulder concentration. The other two were investigated in the field to verify this conclusion.

Details of the pleistocene geology, field investigations and estimates of the boulder concentrations as prepared by M.T.C. personnel and pleistocene geologists with Bird and Hale Ltd., are presented for the Bending Lake Road Study Area. Observations are also presented regarding conditions, including surface and/or buried boulder concentrations, which occur in the Hwy. 631 and Dubreuilville Road study areas.

All figure numbers referred to in the following text are presented in Appendix B and ground photographs are included in Appendix C.

2.5.1 Bending Lake Road

Pleistocene Geology

Glacial advance in this area was from a northeasterly direction. Three types of landforms exist along the alignment: glacial, lacustrine and fluvial.

Glacial Deposits

Glacial action has built an end moraine which locally exceeds 50 metres relief. Its upper surface is highly modified by post-glacial lake action. The moraine lacks a more traditional hummocky upper surface. Indeed, relief often changes less than two metres over a distance of one kilometre (0.2% slope).

Two till sheets are recognized within the moraine as evidenced in shallow (1.5 m deep) borehole data from M.T.C. Other till sheets may be present; however, they were not encountered in these boreholes. The following details result from analysis of these borehole data.

The upper till sheet is dark brown, occasionally rusty brown, and rarely grey. It has an average thickness of about 0.3 m but ranges from 0 to 1 m. It is a fine to

medium sandy, often silty loam, and is usually overlain by 10 to 12 cm of topsoil. Borehole data indicate that the till has a highly variable boulder content. Some sections are essentially boulder free; other areas are described as "extremely bouldery". Surface boulders up to 4 m diameter have been observed. These boulders that extend up to 3 m above the present surface layer and boulder pavement are the result of the original surface material being washed by the "washing" action of glacial melt waters.

The lower till sheet is light brown and is composed of fine to medium, occasionally coarse and gravelly sand. It is locally loamy, and it is usually stony, cobbly and bouldery. Borehole data indicate that this till is over 2 m in thickness. Boulder content is usually high.

Ground moraine, reported as consisting of silty sand till, occurs as a thin localized sheet over bedrock north and south of the end moraine complex.

Lacustrine Deposits

Lacustrine deposits, products of Lake Agassiz, occur locally along the alignment (see Figures 1a and 2a). These deposits consist primarily of sand and gravel with some silt.

The influence of Lake Agassiz was primarily erosional as it modified the surface of the end moraine. The positions of stranded beaches indicate that the moraine was entirely submerged beneath glacial meltwater. Consequently, where bedrock control is absent, wave action has produced a nearly flat top on the moraine. As indicated in Figure 3b, glacial meltwater ran over the moraine as sheet run-off. This washing action resulted in removal of fine materials (sand and gravel) and in surface concentration of boulders on the northeast side and top of the moraine. As the water levels receded the moraine was breached in a number of locations (see Figure 3a) and the flow of water was generally from north to south. Wave and current action on the north side of the moraine was more intense than on the south side and resulted in removal of the fine material, further concentrating the boulders on the north side, as compared to the south side. Numerous raised beaches occur as indicted in Figures 1, 2, and 3.

The finer material, primarily sand and gravel, which was washed over the top of the moraine or through breaches in the moraine was deposited in outwash and beach formations on and adjacent to the south side of the moraine (see Figures 1, 2, and 3).

"Eskers" are noted in the M.T.C. data at four locations. These have reliefs of up to 9 m and run approximately northwesterly. They consist of up to 1.3 m of sand and

gravel over a bouldery core. Boulders up to 3 m in diameter are noted on the surface. These features have since been determined as stranded beaches overlying modified end moraine (see beach deposits, Figure 1a).

Generally, beach deposits on the north side of the moraine consist of high surface concentrations of boulders overlying modified till. Beach deposits on the south side consist of highly variable thicknesses of sand and gravel overlying till.

Fluvial Deposits

These deposits are confined to stream valleys cutting the moraine or outwash deposits. A variable thickness (up to 4.7 metres at 11+400) of sand may have accumulated in and around the sides of present drainages. These deposits are frequently cobbly and gravelly. Some densely packed surface boulder armouring is apparent from the aerial photography. Because these boulders originated in the boulder till, they are large, well in excess of one metre in some areas. Many of the present drainages originated as minor spillways or meltwater channels.

The following conclusions regarding boulder concentrations can be drawn from interpretation of the pleistocene geology and glacial and post-glacial processes.

Lake action has actively removed fines from the upper till layer. Often, all the fines have been removed and this till is reduced to boulder pavement or scattered boulders resting immediately on the lower till unit. Many raised boulder beaches have been constructed by wave action, particularly on the north side of the moraine. In these areas of secondary boulder concentrations, road cuts encounter very high boulder densities and generally, very large boulders. The shallower the cut, the higher the percentage. Deeper cuts, while moving more material, dilute the very high surface density with relatively lower interior densities.

Where fluvial and lacustrine deposits have reached substantial thicknesses, the boulder till of the moraine may be sufficiently buried not to be intersected in road cuts (which are less than 2.5 m). However, all of the accumulations of consequence rest in the topographic lows, because of erosion. Few road cuts are made in these low-lying locations, and on higher ground, deposits are not thick enough to be of major impact in reducing overall boulder concentrations.

In general, the higher ground on the north side of the moraine has increased boulder concentrations. This is

partly due to thinner veneers of lacustrine material and to variations in the degree of washing of the till.

Field Investigations and Estimates of Boulder Concentrations

Field investigations consisted of visual examination and mapping of the pleistocene geology of the study area, estimation of surface and subsurface boulder concentrations at predetermined locations and probing with Pionjar overburden drilling equipment once in the field. The study areas were located in areas that were representative of various landforms; the general areas of the sites (where estimates of boulder concentratons were to be made) were located in areas where the M.T.C. had predicted boulder concentrations; and, the specific locations for visual examinations and probings were identified in the field, where the road cuts provided a good cross-section. Road cuts that contained bedrock were avoided because boulders in these locations may have originated from the bedrock rather than glacially deposited overburden.

Visual examinations were conducted at three sites for which M.T.C. data were available and for which airphoto interpretation-based estimates of boulder concentration had been prepared. Detailed estimates of surface and buried boulder concentrations and probing with Pionjar drill equipment were conducted at these sites.

The concentration of surface boulders was determined by chaining a 3 m by 3m square plot in the deepest portion of the cut, counting the number of boulders greater than 1.0 m in diameter, estimating the average boulder size and calculating the percentage of boulders.

All of the sites selected were in areas of road cuts where the entire vertical cut section was used. Thus it was possible to determine subsurface boulder concentrations, by cleaning a 3 m wide section the full height of the road cut (see Photo No.1 Appendix C). In order to determine the overall boulder concentration, the 3 m by 3 m surface plot was used in conjunction with the entire vertical cut section. The first step was to determine the distinct layers of particle sizes in the vertical face. Once the layers were established, boulders greater than 0.5 m in diameter* in a layer were counted, the average boulder size estimated and the volume occupied by boulders calculated by assuming that the density in the vertical layer was consistent throughout the 3 m by 3 m horizontal plot. The average concentration in the entire cut was determined

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*A smaller diameter was used to define buried vs. surface boulders to reflect the fact that even small, buried boulders may significantly influence construction costs.

by: multiplying the volume of a layer by the percentage that that layer represents in terms of the entire face; and, summing the values of all the layers, thus yielding a weighted average concentration.

Probing with the Pionjar drill equipment consisted of probing on the original ground adjacent to the cuts. There were nine holes placed in an area of 6 m by 6 m with 3 m spacings in an attempt to develop correlations between the surface and subsurface boulder concentrations and refusal with the probing equipment (see Photo No. 2 Appendix C).

Prior to the field investigation, two independent estimates of overall boulder concentrations were prepared by two pleistocene geologists. One estimate was based solely on interpretation of the pleistocene geology and glacial processes through use of airphoto interpretation. The other also incorporated the use of soils information provided by M.T.C. Along the Bending Lake Road alignment, where the landforms are well developed, the two estimates were very close and the figures referred to in this section of the text are an average of the two estimates. Table 1 contains the estimates of boulder concentrations and Table 2 contains a description of how the estimate was prepared using airphoto interpretation and soils data.

Examination of the comparisons between M.T.C. and Bird and Hale Ltd. estimates of total (surface and buried) boulder concentrations indicated large variations for individual cut sections, not just for the Bending Lake Road study area but for the other two study areas as well. These differences in percentage concentrations refer to the overall cut face (or average) in each case, as the M.T.C. estimates were presented in this form. Thus, data on strata having variable boulder concentrations were not available. Consequently, depths and/or volumes of individual cuts were not considered in the comparisons, because such an analysis would be confusing and misleading.

Results of the investigation at the three sites follow. The sites are located on Map 3, Appendix A.

Site 1 Chainage 15+470 to 15+830 (WP 18-77-03)

Subsurface boulder concentrations were determined in two plots. In both cases no subsurface boulders greater than 0.5 m in diameter were observed. Thus a low subsurface boulder concentration is assumed. At both plots, there were 5% boulders 0.2 m to 0.5 m in diameter, numerous cobbles and a high percentage of gravel. The surface boulder concentrations are 20% by area (on the 3 m by 3 m plot). As the surface boulders are remnants of the eroded till material it is assumed that a minimum of 5% boulder

TABLE 1

ESTIMATES OF BOULDER CONCENTRATIONS BENDING LAKE ROAD

SITE NO. (see Map 3 Appendix A)	ROAD CUT (chainage)	MAX. BLD SIZE* (m.)	BEDROCK IN CUT	TYPE OF DEPOSIT **	M.T.C ESTIMATE %	AIRPHOTO INTERP ESTIMATE %***
	10+020 - 10+210	N/A	-	SB	20	20
	10+540 - 10+760	"		SB	--	8
3	(11+000 - 11+130	"	-	SB	30	10
	(11+360 - 11+420	"	-	F	--	1
	11+608 - 11+757	"	-	F ?	20	8
	11+990 - 12+430	"	yes	M	5	15
	12+680 - 13+062	"	yes	MBP	17	20
2	13+400 - 13+570	1.5	-	MSB	10	12
	13+624 - 13+800	2.0	yes	SB	4	8
	13+940 - 14+010	N/A	yes	SB	--	8
	14+520 - 14+720	0.6	-	MSB	--	13
1	15+470 - 15+830	1.8	-	SB	4	12
	16+140 - 16+156	1.0	-	SB	2	5
	16+220 - 16+360	1.0	-	SB	5	12
	16+460 - 16+603	1.0	-	SB	15	12
	16+764 - 16+872	1.0	-	SB	9	13
	16+950 - 17+035	1.0	-	SB	6	10
	17+060 - 17+242	1.0	-	SB	3	8
	17+310 - 17+470	4.0	-	M	2	15
	17+572 - 17+620	N/A	-	M	--	3
	18+280 - 18+700	2.0	-	SB	--	10
	19+250 - 19+505	1.5	-	SB	2	9
	19+824 - 19+835	0.6	-	SB	2	7
	19+955 - 20+252	4.0	-	SB	4	10
	20+435 - 20+590	3.0	-	SB	2	8
	20+652 - 20+780	0.8	-	SB	2	8
	20+900 - 21+080	2.0	-	M	2	8
	21+290 - 21+670	2.0	-	E	2	8
	21+980 - 22+040	0.5	-	LM	--	4
	22+312 - 22+366	1.5	-	LM	2	6
	22+510 - 22+585	2.0	-	SB	2	12
	22+712 - 22+916	1.5	yes	M	--	15
	23+160 - 23+245	2.5	yes	M	--	12

* taken from bore-hole profiles; N/A not available

** SB - stranded beach or beach deposits; F = fluvial deposits; M = moraine;
MBP - modified moraine with boulder pavement; E = esker;
MSB = modified beach with boulder pavement;
LM = lacustrine deposits on moraine

*** Geol. 1, with M.T.C. soils data.

TABLE 2

PROCEDURE USED DURING STUDY FOR TEST AREAS FOR ESTIMATING BOULDER CONCENTRATIONS USING AIRPHOTO INTERPRETATION AND SOILS DATA *

(1) the interpretation from aerial photographs (1:15,840) of the Quaternary geologic history as it pertains to the surficial geology and mapping of these deposits.

(2) the examination of all surficial drainage features for boulders, preferably at an airphoto scale of 1:10,000.

(3) the examination of borehole profile data along the right-of-way with respect to glacial deposits, and the fine-tuning of the previously formulated geological interpretation. Of special interest is the depth to boulder horizons and areas of boulder pavement.

(4) an assessment is then made as to why boulders are present on surface in specific locations of higher density. This is done by reflecting upon what is known of the geologic history.

(5) a typical stratigraphic column of the surficial deposits is assembled on paper.

(6) the highway design is examined and road cuts delineated on plans and profiles.

(7) an assessment is made, utilizing borehole data, as to what volume of the road-cut is in bouldery vs non-bouldery deposits. Bedrock is not included in this calculation.

(8) a estimate of boulder percentage is made to determine what affect the depth of cut will have on surface boulder concentrations since these will be diluted by underlying, perhaps less bouldery material.

(9) if a topographic effect on boulder concentration is noted, the elevation of the cut is determined and initial boulder estimates are adjusted subjectively.

(10) a final, pre-field investigation estimate of boulder concentration is made.

*Note: The above procedure was used in the test areas but does not represent the recommended method.

content exists in the till. Based on a weighted average of surface and subsurface boulder concentration (calculated as explained above), the overall boulder concentration is estimated at 10%.

Nine attempted probes at this site with the drill equipment resulted in refusal at depths less than 2 m. As the subsurface boulder content is low (5%) it is assumed that the probe was encountering refusal on cobbles and coarse gravel. Thus probing does not appear to be a reliable method for determining subsurface boulder concentrations in overburden containing moderate to high percentages of material ranging from coarse gravel to small boulders.

The initial airphoto interpretation, conducted without the aid of M.T.C. soil data or field investigation, resulted in mapping of the area as water-worked end moraine with a thin layer of boulder enrichment at surface. The estimated overall boulder content was 5-10%. A second airphoto interpretation, using M.T.C. soil data, verified that the soil consisted of reworked till and a revised estimate of 12% boulder content. The M.T.C. estimate of boulder content was 4%. The boulder content of 10% determined through field investigation is in agreement with the estimates obtained through airphoto interpretation.

Site 2 Chainage 13+400 to 13+570 (WP 18-77-03)

No subsurface boulders were observed. Thus a low subsurface boulder content is assumed. The soil consists of 5% cobbles and 25% gravel.

The surface boulder content is 30%. At higher elevations south of the alignment, surface boulder concentrations of up to 75% occur.

As the surface boulders are remnants of the eroded till it is assumed that a minimum 5% subsurface boulder content exists. Thus the average overall boulder content of the cut is estimated at 12%.

Nine attempted probes with the Pionjar drill equipment resulted in three refusals and six successful probings beyond the depth of the cut (3-5 m). The high penetration rate indicates that the high boulder concentrations (30%) are restricted to the surface. If the high concentrations occurred at depth, the penetration rate would be much lower due to overlapping of the boulders. It is assumed that some of the refusals were on cobbles and coarse gravel. Thus, this verifies that, in areas with high percentages of cobbles and small boulders, probing is not a reliable method for estimating boulder concentrations.

Investigations indicate that this area is a raised beach remnant on the north slope of the moraine and that boulder

pavements ranging from 30% to 75% of the plan view of the ground, with a maximum boulder size of 2.5 m, occur.

Initial airphoto interpretation indicated the presence of boulder pavement and estimates of 10% overall boulder content were made. Reassessment of the airphoto interpretation, considering the M.T.C. soil data, resulted in 12% overall boulder concentrations. The original estimate by M.T.C. personnel was 10% and the content determined through field investigations was 12%. Generally, all of the estimates are in agreement.

Site 3 Chainage 11+000 to 11+420 (WP 18-17-03)

Five test plots were investigated in this area. This permitted representative sampling of the various landforms occurring in the area and development of a cross-section of the moraine and adjacent beach and outwash deposits (see Figure No. 3b).

Plot A (See Photo No. 1, Appendix C)

This was an area of deposition of the till material. Meltwater flowed over the moraine in sheet runoff, thus removing the fine material (i.e., sand and gravel). This resulted in surface boulder concentrations on the north slope, top and southern brow of the moraine. It appears as if subsequent ponding and beach erosion resulted in further concentration of boulders on the north slope.

Based on a weighted average of surface and subsurface boulder concentrations, the surface plus buried boulder concentration is estimated at 10%.

Nine probes were attempted and all encountered refusal at depths less than 2 m. Thus, it is assumed that refusal was encountered on cobbles and small boulders.

The preliminary airphoto interpretation-based estimated of overall boulder content was 10%. The M.T.C. estimate was 30%. The airphoto interpretation-based estimate is in agreement with the concentration determined by field investigation.

Plot B

The surface stratum (0 to 5 m) consists of sand and gravel containing 10% cobbles. This material was deposited as outwash by meltwater flowing over the top of the moraine. Subsequent reworking by ponded water south of the moraine resulted in the formation of depositional beaches. There are no surface or subsurface boulders in this material.

The subsurface stratum consists of till of unknown depth. There is no concentration of boulders at the till-outwash

interface and the average content of bulders greater than 1 m diameter is 12%. Eight out of nine probes did not encounter refusal. This indicates the unreliable nature of probing to determine boulder concentration.

The airphoto interpretation-based estimates of boulders was 1% and M.T.C. personnel did not provide an estimate for this site. The discrepancy between the airphoto interpretation-determined estimate and the field-determined estimate (1% to 12%) indicates the tendency of the outwash material to mask the boulder content of the underlying till.

Plot C

The entire road cut in this area consists of outwash sand and gravel deposits and there are no surface or subsurface boulders.

Three probes to depths in excess of the cut did not encounter refusal.

Preliminary airphoto interpretation resulted in an estimate of 1% boulder concentration. M.T.C. personnel did not prepare estimates for this area. The airphoto interpretation-based estimate is in agreement with the actual overall boulder concentration.

Plot D

This site is within an area of the moraine which was breached by meltwater. The soil consists of outwash sand and gravel and valley fill material. There are no surface or subsurface boulders visible in the road cut.

Plot E

The valley floor consists of an area of highly waterworked till. The fine material was removed and the content of surface and subsurface boulders are 50% and 20% respectively. Estimates of the boulder content in this area had not been prepared by M.T.C. personnel. Prior to field investigations, Bird and Hale Ltd. prepared a boulder estimate based on airphoto interpretation; however, in the field the road was found to be in a different location than indicated on the airphotos.

The results of investigations of the Bending Lake Road are summarized in Table 3. These results permit the following conclusions to be drawn. Airphoto interpretation is a valuable tool to assist in interpretation of the pleistocene geology and glacial and post-glacial processes. Interpretation of these criteria appears to be a reliable method of estimating approximate concentrations of surface and subsurface boulders. The reliability of this method

increases, when supplemented by field investigations conducted by personnel with a strong background in pleistocene geology. Regarding the Bending Lake Road, the depositional features on the south side, as opposed to the erosional features on the north side of the end moraine have considerably lower concentrations of surface and shallow subsurface boulders. Thus, sections of the alignment located on the south side encountered lower concentrations of boulders than those on the north side.

The best results, in terms of accuracy, are those determined through calculating the weighted average for cut faces. The Pionjar overburden drilling equipment does not appear to be a very reliable method for estimating subsurface boulder concentrations and it has limited applications. It would be useful in the case of a surface layer of boulders overlying boulder-free material, as it would confirm the absence of subsurface boulders. In the case of a boulder-free material overlying bedrock or material with high boulder concentrations, it is useful in determining the approximate depth to the boulder or bedrock layer. However, to ensure a reasonable level of confidence in the data, a large number of test sites are required; and, use of this equipment may be impractical.

TABLE 3

Bending Lake Road
Estimated Boulder Concentrations in Cut Sections

Site No. (see Map 3 Appendix A)	Chainage (M.T.C.)	Boulder Concentration Estimates (percentages)			
		M.T.C.	Bird and Hale Ltd. Geol.1	Geol.2*	Field
1.	15+470-15+830	4	5-10	12	10
2.	13+400-13+570	10	10	12	12
3.	11+000-11+420				
A		30	10	8	10
B		-	1	-	12
C		-	1	-	1
D		-	-	-	0
E		-	-	-	25

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*Geol.2 made use of M.T.C. soils data.

2.5.2 Highway 631 - White River

As previously mentioned, it was decided that Highway 631 was not a suitable location to attempt to develop a method for determining boulder concentrations. However, airphoto interpretation was conducted, preliminary estimates of boulder concentrations were prepared and limited field investigations were conducted, to verify the conclusions determined in the Bending Lake Road study area. Observations from these investigations follow. However, the general observation is that due to the poorly developed nature of the landforms and shallow depth of overburden over the majority of the area, the proposed method of interpreting the pleistocene geology and inferring boulder concentrations is not applicable.

Pleistocene Geology

Relief varies by up to 130 m along the right-of-way. Slopes from 0.3% to 8% over 300 m are encountered.

Topography is controlled by Precambrian crystalline bedrock and by compacted glacial till. To a much lesser extent, ground moraine and outwash deposits exert local control.

Shallow road cuts (<2 m), and road cuts in outwash deposits, tend to encounter few boulders. Deeper cuts (>2 m), and cuts where the right-of-way climbs bedrock ridges, encounter higher boulder concentrations.

Ice advance was from a northeast direction. Only one form of glacial deposit is noted along the highway route. A layer of bouldery ground moraine was deposited during ice advance. This material was overlain locally by a succession of outwash deposits. This glacial deposit is composed of sand and silt with a varying boulder content estimated to average 25%. Boulder size, as revealed along many lakeshores and streambeds, may locally exceed 5 m. However, an average size of 1 to 1.5 m is thought to be representative of the boulders. Along drainages and some beaches, finer-grained fractions have been eroded and later deposited in sheltered bays to produce sand beaches. The moraine has been deposited atop either bedrock or highly compacted till and the reworking of the till has produced short sections of boulder pavement.

Locally, outwash silts, sands and gravels have been deposited on top of the ground moraine. Four distinct stratigraphic units are recognized from the M.T.C. data, although not all are uniformly present. Units frequently pinch out in an up-slope direction. On some slopes, slumping or sloughing off of some outwash material has disturbed the regular stratigraphy. The total thickness of these deposits seldom exceeds 2 m. Outwash deposits

were formed following modification of the ground moraine by initial glacial runoff. Thicker accumulations of outwash materials are found on lower lying ground. Materials deposited on moderately sloping land tend to be coarser than sediments laid down on more level terrain.

In summary, the shallow, poorly developed landforms were subjected only to minor modifications through glacial and post-glacial processes (see Photos 3 and 4, Appendix C). Localized bedrock outcrops were difficult to distinguish from large boulders, both on airphotos and during the field investigations. Therefore, it would be meaningless to state the percent boulder concentrations. The difficulties of predictions of surface and/or buried boulder concentrations at five cut sections are illustrated in Table 4. The lack of consistency among the M.T.C. predictions and those of Bird and Hale Ltd. geologists are clear. Thus, it is evident that this study area did not have the necessary geological characteristics to test a method to estimate surface and/or buried boulder concentrations.

TABLE 4

Highway 631 - White River
Estimated Boulder Concentrations in Cut Sections

Site No. (see Map 4 Appendix A)	Chainage (M.T.C.)	Boulder Concentration Estimates (percentages) M.T.C.	Bird & Hale Geol.1	Geol.2*
1.	194+50-211+80	-	10+	0-12
2.	219+80-220+50	10	5-10	1
3.	282+30-283+50	-	0- 5	0- 2
4.	397+00-407+50	8	5-15	10-12
5.	493+40-497+10	5	2	6- 8

*Geol.2 made use of M.T.C. soils data.

2.5.3 Dubreuilville Road

The location of the portion of the highway studied is shown on Map 5, Appendix A.

Pleistocene Geology

Surficial deposits are composed of an upper sequence of

outwash, and a lower horizon of bouldery ground moraine. An esker strikes approximately NE-SW through the town of Dubreuilville.

Shallow road cuts (<1.5 m) in outwash deposits encounter few boulders. Deep cuts (>1.5 m) in outwash deposits may cut through the underlying moraine, and thus contain higher buried boulder concentrations. Cuts in higher ground tend to penetrate shallower outwash deposits and therfore proportionately greater depths of ground moraine.

Despite the presence of an esker in the town of Dubreuilville, only one type of glacial deposit is encountered along the roadway. A layer of ground moraine, resting on bedrock, was deposited throughout the area during ice advance. It is overlain by two successions of outwash deposits which were deposited when the glacial ice withdrew from the area. In low lying areas and areas of local ponding, organic deposits accumulated. Perhaps in response to a minor ice readvance, a surge of outwash material buried some of these organics. Locally, mixing of sand and organics has occurred. With final ice withdrawal, the deposition of outwash debris eased. The end result of these glacial actions is an uneven distribution of deposits throughout the area. Thus, some areas have been completely washed and eroded, leaving boulders on bedrock, while other areas exhibit a relatively consistent layer of ground moraine. In addition, outwash deposits are unevenly distributed over the ground moraine. Subsequent development of marshes, bogs and swamps has led to the accumulation of deep organic sediments in surficial and bedrock depressions.

Bouldery ground moraine appears to be common throughout the region. The matrix consists of gravelly sand. From airphoto interpretation, the boulders appear to be 2-4 m in diameter. The exact boulder content of this moraine is unknown, although an estimate of 20% is probably reasonable. It is best observed where lakes and streams have eroded the flanks of hills, thus removing the overlying deposits. Several rapids occur along the Magpie River, approximately 7 km west of Dubreuilville, where the surface deposits have been removed. The moraine has frequently been eroded and removed from the bedrock surface, presumably by early glacial meltwater. This process has been most active where the bedrock is highly sloping.

A series of outwash sands, silts and gravels has been deposited atop the ground moraine. Where the moraine is absent, the outwash materials rest immediately upon bedrock. The thickness of these materials exceeds 4 m but is highly variable depending upon terrain, slopes and specific locations. Few notations in M.T.C. data are made regarding boulders on the surface. Therefore, it is reasonable to assume that outwash deposition buried what-

ever boulders protrude from the ground moraine cover.

Organic deposits have accumulated in bedrock depressions. Locally, the ground moraine or outwash material influences the surface topography. Neither are impermeable enough to result in surface ponding and therefore organic deposits at higher topographic elevations. Organic accumulations in excess of 4 m have been noted in the M.T.C. data.

During the field investigation, six plots located as shown on Map No. 5, Appendix A, were examined. Photo No. 5, Appendix C, illustrates the shallow till typical of the area. The high surface boulder concentrations shown in Photo No. 6, Appendix C, demonstrates the increased reworking of the till and extensive removal of the fines on steeply sloping topography. These surface boulder concentrations are localized because of the influence of topography, controlled by the crystalline rocks directly beneath the surface boulders.

The total boulder estimates for each of the six sites examined are given in Table 5. Large variations in estimated concentrations among M.T.C. personnel and the two geologists from Bird and Hale Ltd. are evident.

TABLE 5

Dubreuilville Road
Estimated Boulder Concentrations in Cut Sections

Site No. (See Map 5, Appendix A)	Chainage (M.T.C.)	Boulder Concentration Estimates (percentages) M.T.C.	Bird & Hale Geol.1	Geol.2*
1.	17+400-17+500	0	0	0
2.	12+105-12+360	-	2	5
3.	13+600-13+710	-	10+	1- 3
4.	16+274-16+414	2	5	3- 6
5.	16+580-16+930	5-10	10	8-10
6.	17+770-17+870	15	15	2- 4

*Geol.2 made use of M.T.C. soils data.

In summary, the dominant landform in this study area consists of a shallow, bouldery glacial till that has localized areas overlain by outwash. This poorly developed till landform has been subjected to glacial processes

resulting in the removal of fines, primarily on steeper slopes controlled by underlying bedrock. Therefore, localized surface boulder concentrations on steeper slopes are evident from ground observations, but not always on airphotos. This is illustrated on Photo No. 6, Appendix C, by the variable density of treed vegetation in this particular area.

This study area does not have the necessary geological characteristics to test a method to estimate either surface and/or buried boulder concentrations.

3. RECOMMENDATIONS

A method to aid in the estimation of surface and/or buried boulder concentrations was developed through the application of techniques described in Section 2.5 of this report. The recommended procedure, set out in Section 3.4, incorporates specific data recording requirements and specific procedures.

3.1 Remote Sensing Methods and Interpretation of Data

Black and white panchromatic aerial photography should be used as the remote sensing format. Both small and large contact scale photographs are required to thoroughly examine both the regional and specific geological conditions and the effects of glacial and post-glacial processes. Available airphotos from government agencies are suitable, as the scale of these photographs meet the requirements, and the leaf cover conditions are not important.

The interpretation of remotely sensed data must be undertaken by personnel who are experienced in pleistocene geology and glacial processes when estimates of surface and/or buried boulder concentrations are required. The interpretation of terrain pattern elements alone should not be used as a guide for estimating surface and/or subsurface boulder concentrations.

Regarding future investigations involving the acquisition and interpretation of airphotos, consideration should be given to the use of colour infrared photography acquired in early spring under active growth conditions.

3.2 Factors Controlling Boulder Concentrations

Landform type and geological processes (glacial and post-glacial) should be examined in detail to estimate surface and/or buried boulder concentrations. The glacial landforms capable of containing large total boulder concentrations are known. These landforms, if they exist within an area being examined for boulder concentrations, must be identified, if possible. When these landforms are poorly developed and shallow, their identification is very difficult. As the most important factor controlling surface and/or buried boulder concentrations is the effects of glacial and post-glacial processes, the previously stated need for experience in pleistocene processes is again emphasized.

3.3 Case Studies

Further case studies using remote sensing should be undertaken only on areas where the landforms are well developed and are of sufficient depth that the landforms, and not

bedrock, control the topography. In this study, the Bending Lake Road area satisfied these requirements, while Highway 631 and the Dubreuilville Road did not.

It is important that further case studies undertaken by or for the Ministry of Transportation and Communications regarding surface and/or buried boulder concentrations utilizing the method stated in this Section be carefully documented and cross-referenced. Thus, a file of boulder related studies would be established, which would greatly assist in refinement of the method proposed in this study.

3.4 Recommended Procedure for Estimating Boulder Concentrations

A prerequisite for a study established to estimate the surface and/or buried boulder concentration in an area is the involvement of airphoto interpretation personnel with a strong background in pleistocene geology.

(a) Data Acquisition and Review

All relevant publications, maps and papers pertaining to the geology of the area should be obtained. Also, contacts should be made with government personnel, mining companies, aggregate producers and university staff members familiar with the area under study regarding geological conditions and processes.

The information obtained above relating to the pleistocene and bedrock geology should be reviewed and mapped where applicable. The distance to be covered on each side of the proposed route is dependent upon the scale of the geological features. This distance must extend, at a minimum, to the nearest major landform and/or topographic change, as the objective involves identification of the underlying materials.

(b) Preliminary Airphoto Interpretation

Small scale airphoto coverage (1:30,000; 1:60,000), if available, should be obtained for the area under investigation. As these photographs would normally extend well beyond the boundaries of the area under investigation, an overview would be provided. This would permit interpretation of the regional glacial and post-glacial history. The result of this interpretation should be compared with the results of the data reviewed and both agreements and anomalies should be noted.

The larger scale airphotos (1:10,000 or 1:15,840, as available) would then be acquired for the area. These are used to map and identify the landforms; map the surface boulder concentrations; refine the glacial history of the area and map specific areas affected, such as washed beach ridges, large gullies, etc.; and, map the relative surface

and buried boulder concentrations (estimated) of various landforms. These concentrations will likely vary with depth, depending upon this analysis, due to the positions of underlying landforms.

(c) Reconnaissance Field Investigations

A field investigation of pre-selected points on the airphotos should be carried out to:

(i) Confirm the interpretation of the landforms and geological processes previously identified.

(ii) Quantify the surface and/or buried boulder concentrations interpreted from the airphotos and thus attach ranges of percentage boulder content to each category. This should be done for all landforms, even those with low or no boulder contents, although most of the field investigation time should be spent in areas of high boulder concentrations.

(iii) Observe and map surface boulder concentrations, generally in an area up to 2 km on each side of the right-of-way, but depending upon the flexibility of relocating the right-of-way.

(iv) Note the boulder rock types to determine the effect of distance of glacial transport in relation to the hardness of the rocks.

The preselected check points should concentrate on stream banks, lake shorelines, and bare soil areas caused by erosion, road cuts, etc. If the area is inaccessible, the equipment will be limited to hand augers and shovels. Under this limitation, the results will not be as reliable. Depending upon the geology of the area, the predictability becomes very low to nil. At this point, consideration could be given to stopping the investigation. However, this would normally be unwise as the information to be acquired in further stages is useful for alignment variations, etc. If it is accessible, power equipment such as bulldozers and backhoes would yield more information.

(d) Final Airphoto Interpretation

Based on the results of the preliminary field work, the factors interpreted in the preliminary interpretation should be modified accordingly. Actual surface and buried boulder concentrations should be shown at the field points points separately, if possible. The check points should also be carefully logged with regard to soil strata and landform changes. These data can then be extrapolated to other areas having similar characteristics, providing that the landforms and glacial processes are thoroughly understood.

At this stage, it would be appropriate to finalize the route alignment to avoid cuts in areas of high surface and/or buried boulder concentrations, where possible.

(e) Final Detailed Field Investigations

This would consist of verifying the location of the final alignment relative to the landforms having high boulder concentrations. Also, areas where the boulder content has been extrapolated from the preliminary field investigation should be tested along the selected alignment.

If access is available or can be provided economically for tracked power equipment, testing using this equipment would be particularly useful at this stage.

Mr. Bill Moore of our firm discussed the recommended method with Mr. Ray Girard, Head, Geotechnical Section, Northwestern Region, M.T.C., on January 3, 1984. The method used by his office was similar to our recommended method, with the exception that they do not:

(i) Interpret the airphotos for landforms and glacial processes.

(ii) Have direct involvement of staff having both a strong background in pleistocene geology and air-photo interpretation.

(iii) Undertake both reconnaissance and final field investigations (only one field investigation program occurs).

The recommended procedure can be terminated at various points, depending upon the findings at that time. The procedure would have to be carried out at least to include step (c). Based on the results of this investigation, the estimations of surface and/or buried boulder concentration at this stage would be accurate to within plus or minus 50 percent at the best. For example, if the true total boulder concentration is 10 percent, the estimated range would be from 5 to 15 percent. If the procedure is completed fully to the end of step (e), the estimates of surface and/or buried boulder concentrations would likely be within 20 percent. Thus the range for the true total boulder concentration of 10 percent would result in an estimated range of 8 to 12 percent. For these reasons, it is strongly recommended that the complete procedure be implemented. Moreover, according to M.T.C. personnel, this would be an improvement over existing levels of accuracy.

APPENDIX A

AVAILABLE MAPS AND PUBLICATIONS

AND KEY MAPS OF STUDY AREAS

MAP No. 1 - SURFICIAL GEOLOGY LEGEND

1. Ground moraine.

- *Silty to sandy till.*
- *Clayey till.*

2. End moraine, interlobate moraine; sand, gravel and boulders.

- *Unmodified by overriding or by lake action.*
- *Modified by overriding.*
- *Modified by lake action.*

3. Esker, eskar complex, kame; sand, gravel, boulders.

- *Unmodified by overriding or by lake action.*
- *Modified by overriding. (Not mapped on this sheet area)*
- *Modified by lake action; esker and delta complex.*

4. Lacustrine deposits; varved clay, silt, fine sand, sand.

- *Varved clay and silt.*
- *Fine sand.*
- *Sand.*
- *Deltaic sand, valley train.*

5. Outwash deposits.

- *Sand, fine sand, gravel.*

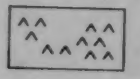
6. Aeolian deposits; fine sand, silt.

- *Loess.*

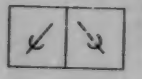
7. Bare bedrock, eroded by lake action.

SYMBOLS

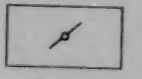
Minor moraines, including washboard and ribbed moraines.



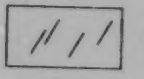
Dune areas; symbol approximates orientation of individual dunes.



Glacial Striae; older.

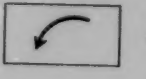


Drumlin, drumlinoid ridge.



Glacial fluting, linear drift pattern.

Raised shorelines.



Spillway channels.

SOURCE: SURFICIAL GEOLOGY MAP S 165
ONTARIO DEPT. OF LANDS AND FORESTS, 1965

MAP No. 1 - SURFICIAL GEOLOGY

SCALE 1 : 506,880

SOURCE : SURFICIAL GEOLOGY MAP S 165
ONTARIO DEPT. OF LANDS AND FORESTS, 1965

MAP No. 2 - ENGINEERING GEOLOGY TERRAIN LEGEND

LANDFORM

MORAINAL

- **ME** *End moraine*
- **MG** *Ground moraine*
- **MH** *Hummocky moraine*

GLACIOFLUVIAL

- **GD** *Ice contact delta, esker delta, kame delta, delta moraine*
- **GE** *Esker, esker complex, crevasse filling*
- **GK** *Kame, kame field, kame terrace, kame moraine*
- **GO** *Outwash plain, valley train*

GLACIOLACUSTRINE

- **LB** *Raised (abandoned) beach form*
- **LD** *Glaciolacustrine delta*
- **LP** *Glaciolacustrine plain*

ALLUVIAL

- **AP** *Alluvial plain*

COLLUVIAL

- **CB** *Slope failure*
- **CT** *Talus pile*
- **CW** *Slopewash and debris creep sheet; minor talus*

EOLIAN

- **ED** *Sand dunes*

ORGANIC

- **OT** *Organic terrain*

BEDROCK

- **RL** *Bedrock plateau*
- **RM** *Bedrock knob*
- **RP** *Bedrock plain*
- **RR** *Bedrock ridge*
- **/R** *Bedrock below a drift veneer*

MATERIAL

- **b** *boulders, bouldery*
- **c** *clay, clayey*
- **g** *gravel, gravelly*
- **p** *peat, muck*
- **r** *rubble*
- **s** *sand, sandy*
- **m** *silt, silty*
- **t** *till*

TOPOGRAPHY

LOCAL RELIEF

- **H** *Mainly high local relief*
- **M** *Mainly moderate local relief*
- **L** *Mainly low local relief*

VARIETY

- **c** *channelled*
- **d** *dissected, gullied*
- **j** *jagged, rugged, cliffed*
- **j^v** *cliffed volcanic rock signature*
- **k** *kettled, pitted*
- **n** *knobby, hummocky*
- **p** *plain*
- **r** *ridged*
- **s** *sloping*
- **t** *terraced*
- **u** *undulating to rolling*
- **w** *washed, reworked*

DRAINAGE

SURFACE CONDITION

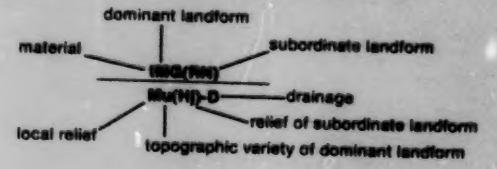
- **W** *Wet*
- **D** *Dry*
- **M** *Mixed wet and dry*
- **h** *Suspected high water table*

The letter codes describing the terrain units are made up of four components arranged as follows: –

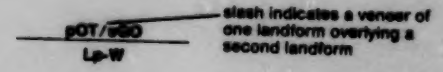
MATERIAL	LANDFORM
TOPOGRAPHY	DRAINAGE

Examples:

1.



2.



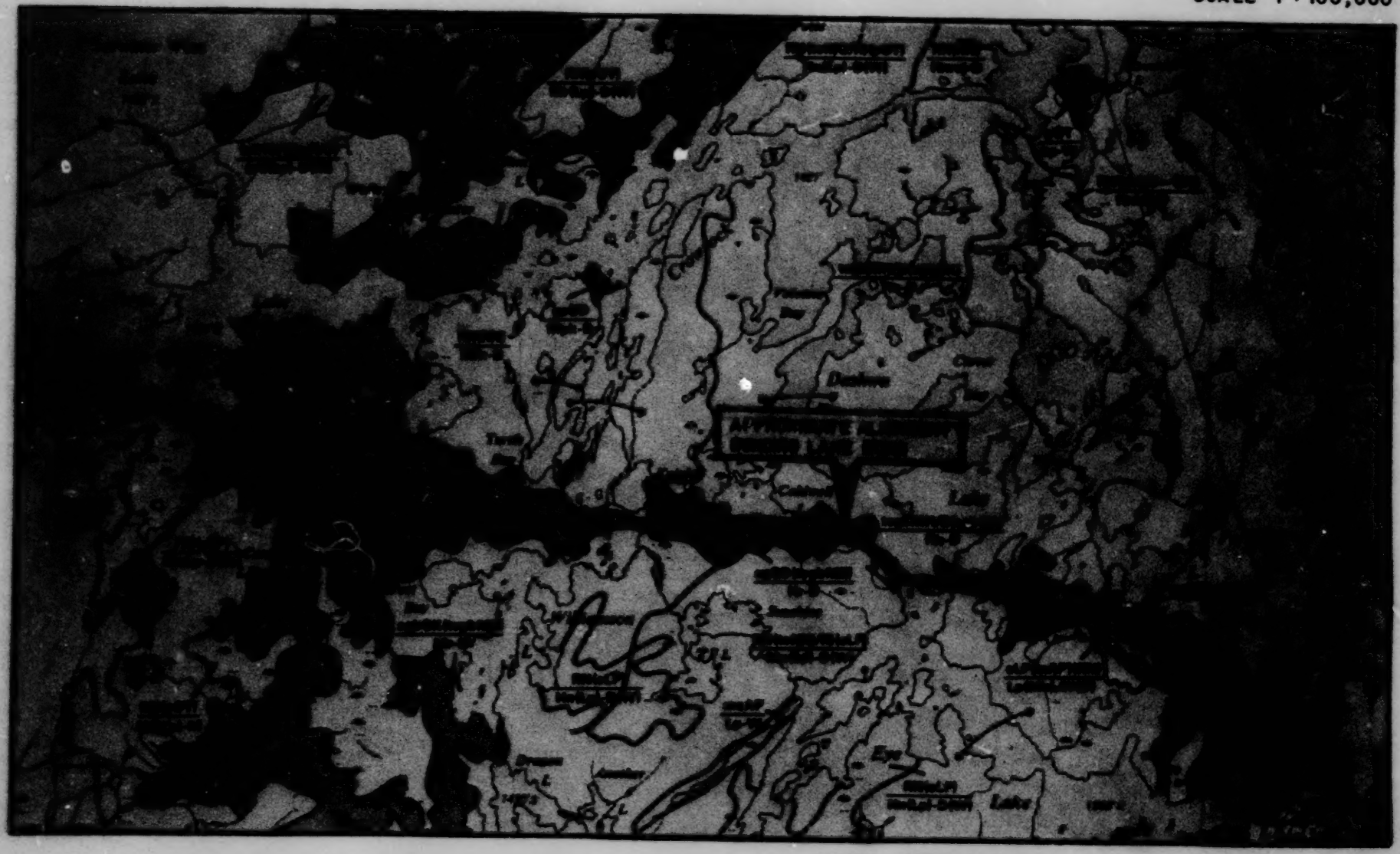
SYMBOLS

- *Significant end moraine or linear moraine-like feature*
- *Well expressed drumlins and drumlinoid ridges*
- *All other linear ice-flow features*
- *Esker ridge (continuous, discontinuous; the symbol does not indicate direction of flow)*
- *Abandoned shoreline (continuous, discontinuous)*
- *Local dune area (type and location of individual dunes not indicated)*
- *Abandoned river channel, spillway, or ice marginal channels*
- *Escarpment*
- ●10 *Sample location*
- *Small landslide scar*
- *Sand or gravel pit*
- *Quarry or mine workings evident from airphotos or field observation (crossed picks are shown in the area of open excavation)*
- *Other man-made features (rock dumps, tailings, lagoons, landfills, etc.: type of feature mentioned where identifiable)*
- *Steep-walled valleys, often bedrock-controlled features*
- *Talus (defined, inferred; base of talus triangle indicates downslope side of escarpment)*
- *Line joining the same terrain units*

SOURCE : NORTHERN ONTARIO ENGINEERING GEOLOGY TERRAIN STUDY - ONTARIO GEOLOGICAL SURVEY.

MAP No. 2 - ENGINEERING GEOLOGY TERRAIN STUDY

SCALE 1 : 100,000



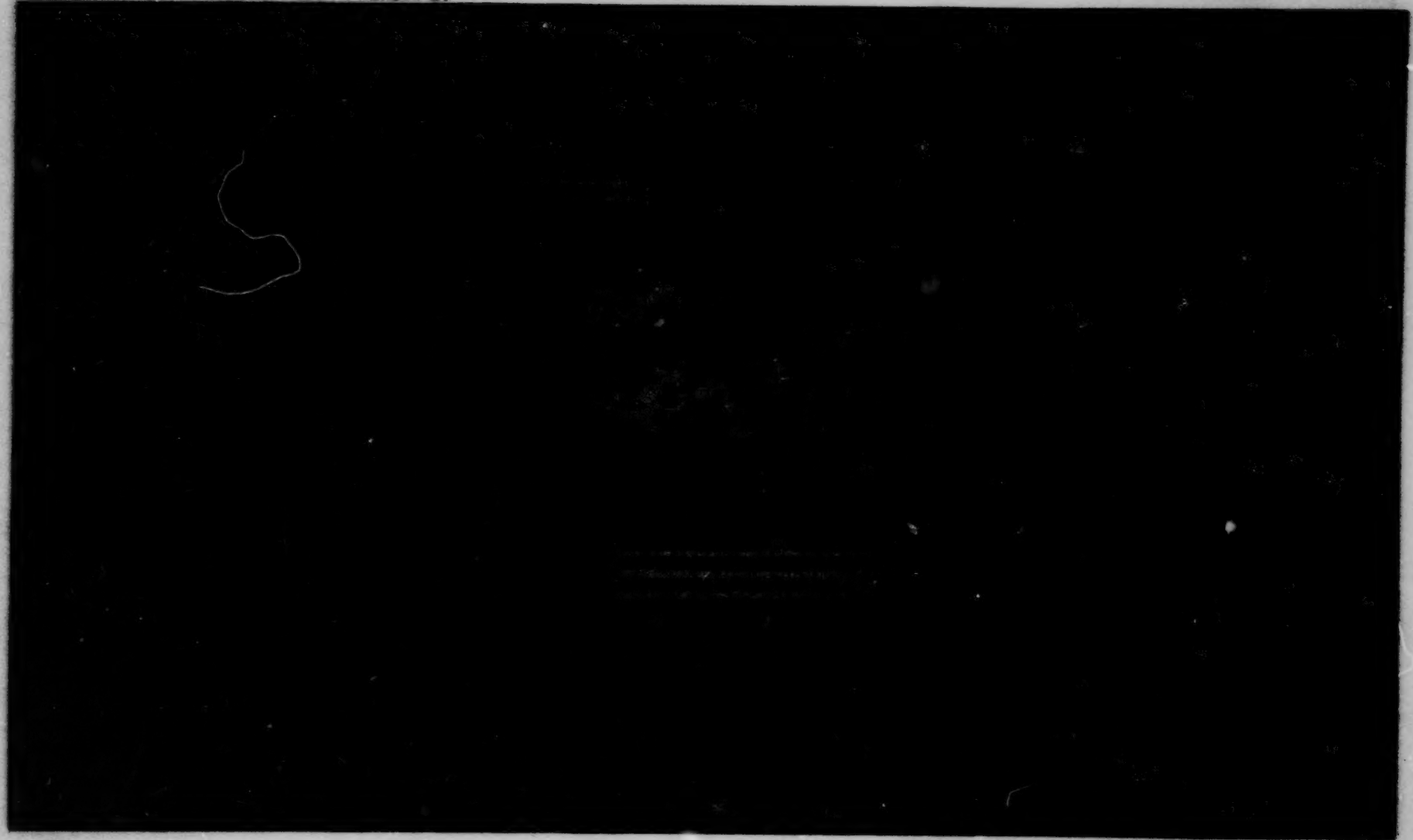
SOURCE: NORTHERN ONTARIO ENGINEERING GEOLOGY
TERRAIN STUDY - MAP 5073 - ONT. GEOLOGICAL SURVEY.

LEGEND

GROUND PHOTOGRAPH (SEE APPENDIX C)
FIGURE NUMBERS (SEE APPENDIX B)

MAP No. 3 - BENDING LAKE ROAD

SCALE 1 : 250,000



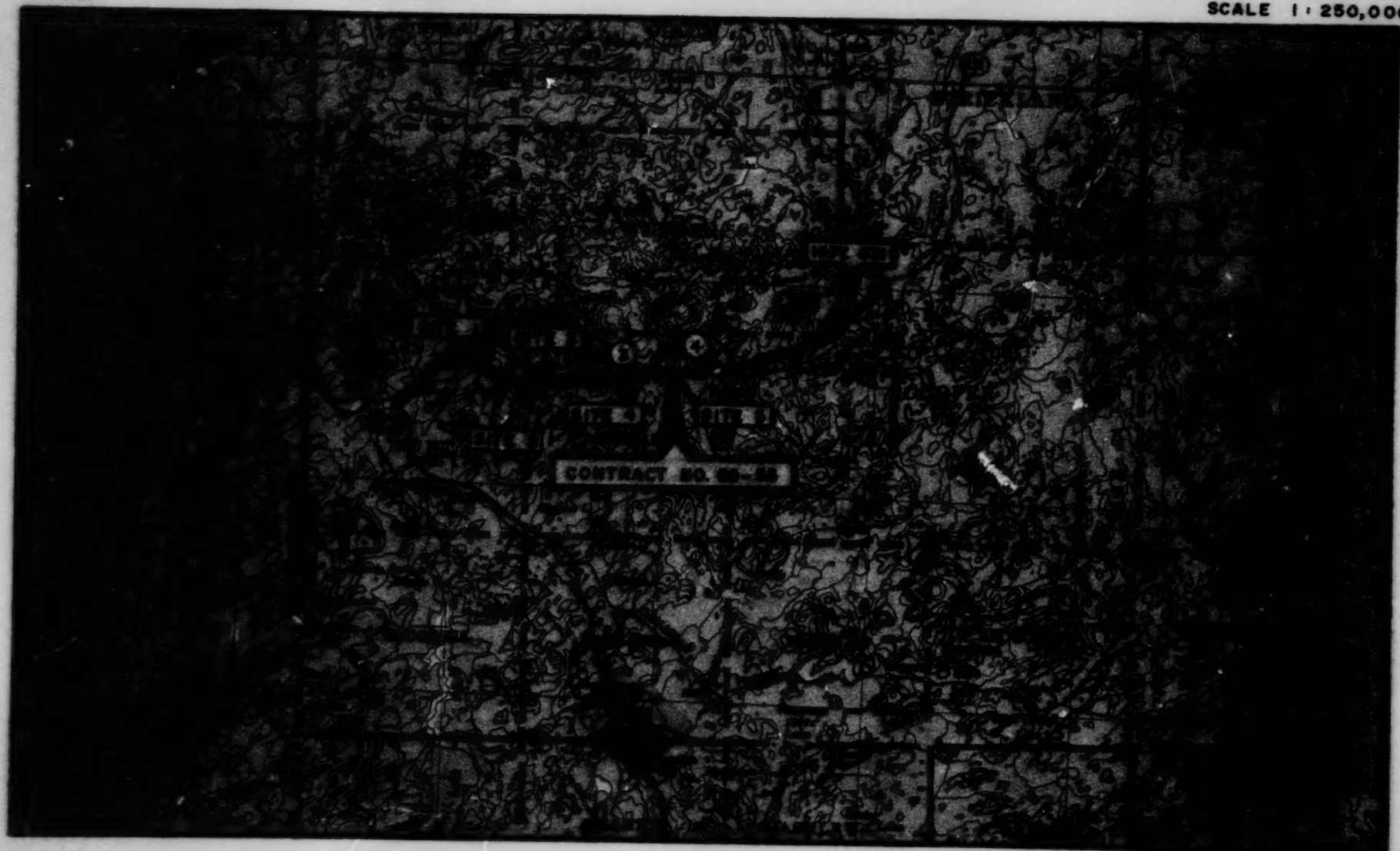
SOURCE : NATIONAL TOPOGRAPHIC SYSTEM MAPS 52G, 52F, 52C, 52B

LEGEND

④ GROUND PHOTOGRAPH (SEE APPENDIX C)

MAP No. 4 - HIGHWAY No. 631, WHITE RIVER

SCALE 1 : 250,000



SOURCE : NATIONAL TOPOGRAPHIC SYSTEM
MAP 42 C, WHITE RIVER

LEGEND

(5) GROUND PHOTOGRAPH (SEE APPENDIX C)

MAP No. 5 - DUBREUILVILLE ROAD

SCALE 1 : 250,000

SOURCE : NATIONAL TOPOGRAPHIC SYSTEM
MAP 42 C, WHITE RIVER

APPENDIX B

GEOLOGICAL INTERPRETATION AND CROSS-SECTIONS ILLUSTRATING GEOLOGICAL FORMATIONS AND PROCESSES

LEGEND

GEOLOGICAL INTERPRETATION AND CROSS-SECTIONS

gl - glacio-lacustrine deposits

- shallow lake laid deposits of sand and gravel overlying end moraine (glacial till)

em - end moraine modified by water currents

- erosional beaches formed, resulting in removal of fine-grained material and concentration of boulders on surface

bd - beach deposits

- depositional beach, beach ridges, consist primarily of sand and gravel and overlying end moraine (glacial till)

od - outwash deposits

- sand and gravel

sb - surface boulders

- surface concentration of boulders or boulder pavement, visible in aerial photographs

gm - ground moraine

- silty to sandy till

- (rb) raised beach

- erosional or depositional

- V-shaped gully

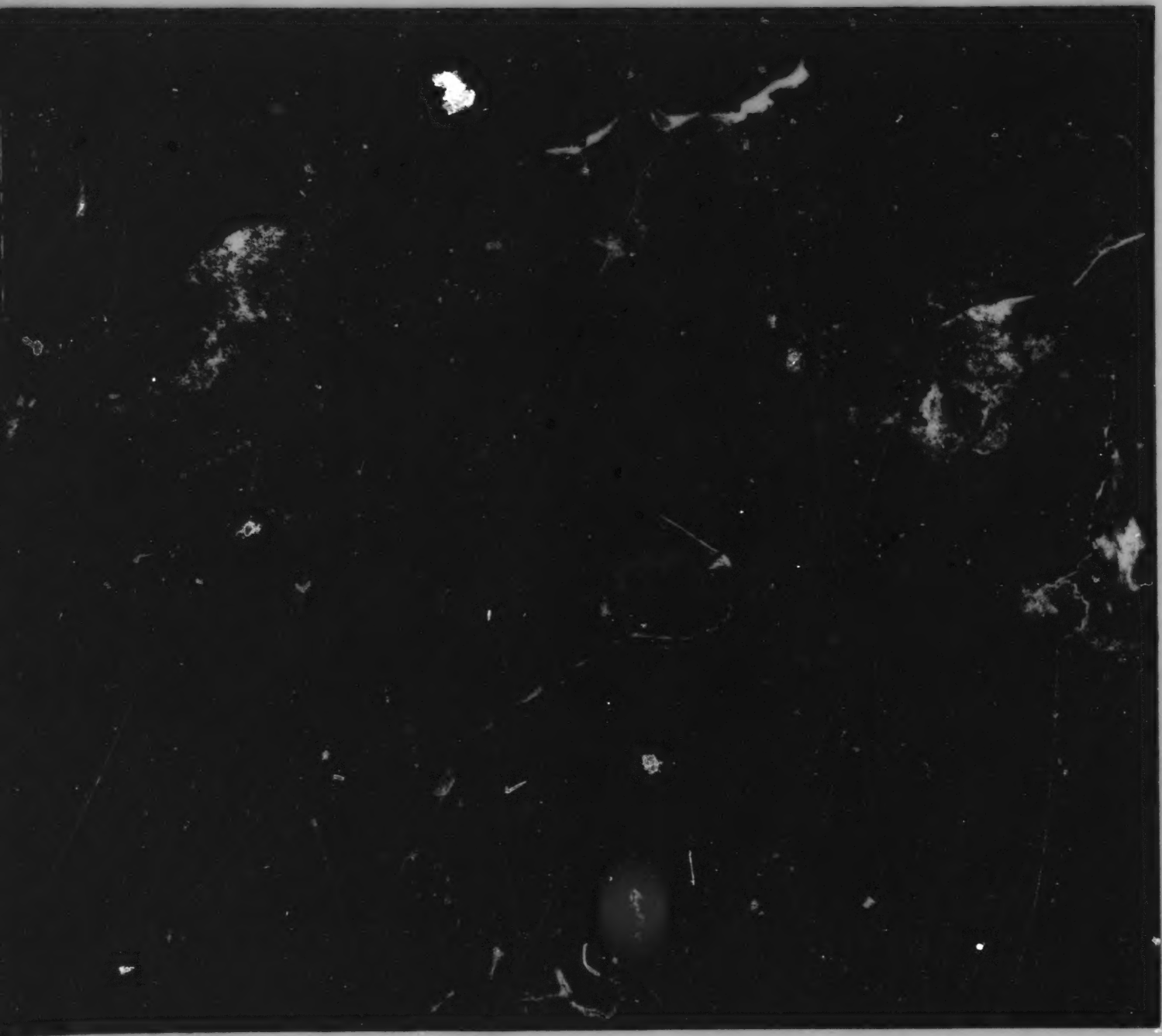


FIGURE 1a

GEOLOGICAL INTERPRETATION

BENDING LAKE ROAD

(WP 18-77-03, CHAINAGE 135+00)

SCALE 1:15840
DATE OF PHOTOGRAPHY: 1977

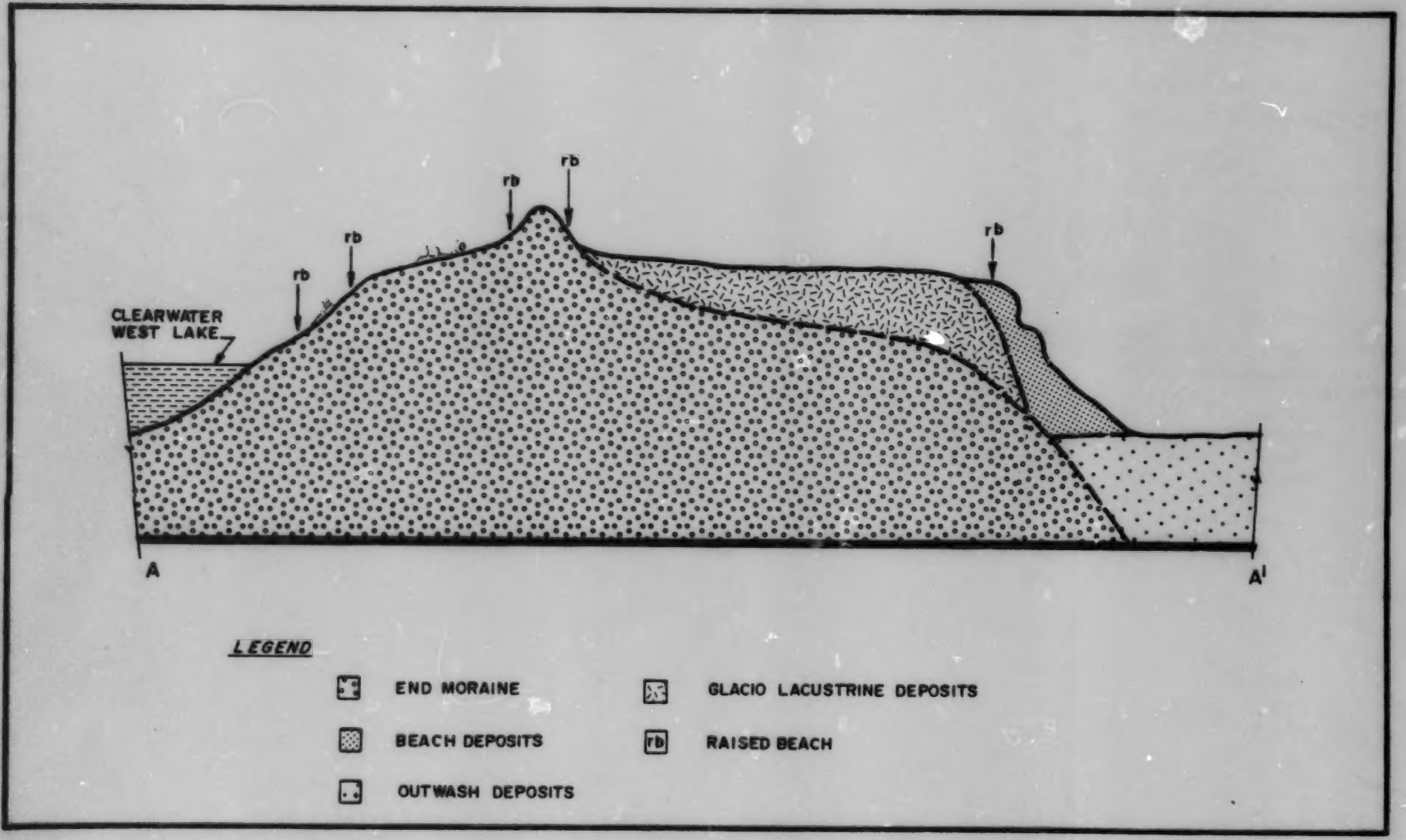
LEGEND

gl - GLACIOLACUSTRINE DEPOSITS
em - END MORAINE, WORKED BY WATER CURRENT
bd - BEACH DEPOSITS
od - OUTWASH DEPOSITS
gm - GROUND MORAINE
sb - SURFACE BOULDERS
- RAISED BEACH
- V SHAPED GULLY

FIGURE No. 1b CROSS - SECTION A-A

NOT TO SCALE

(SEE FIGURE No. 1a)



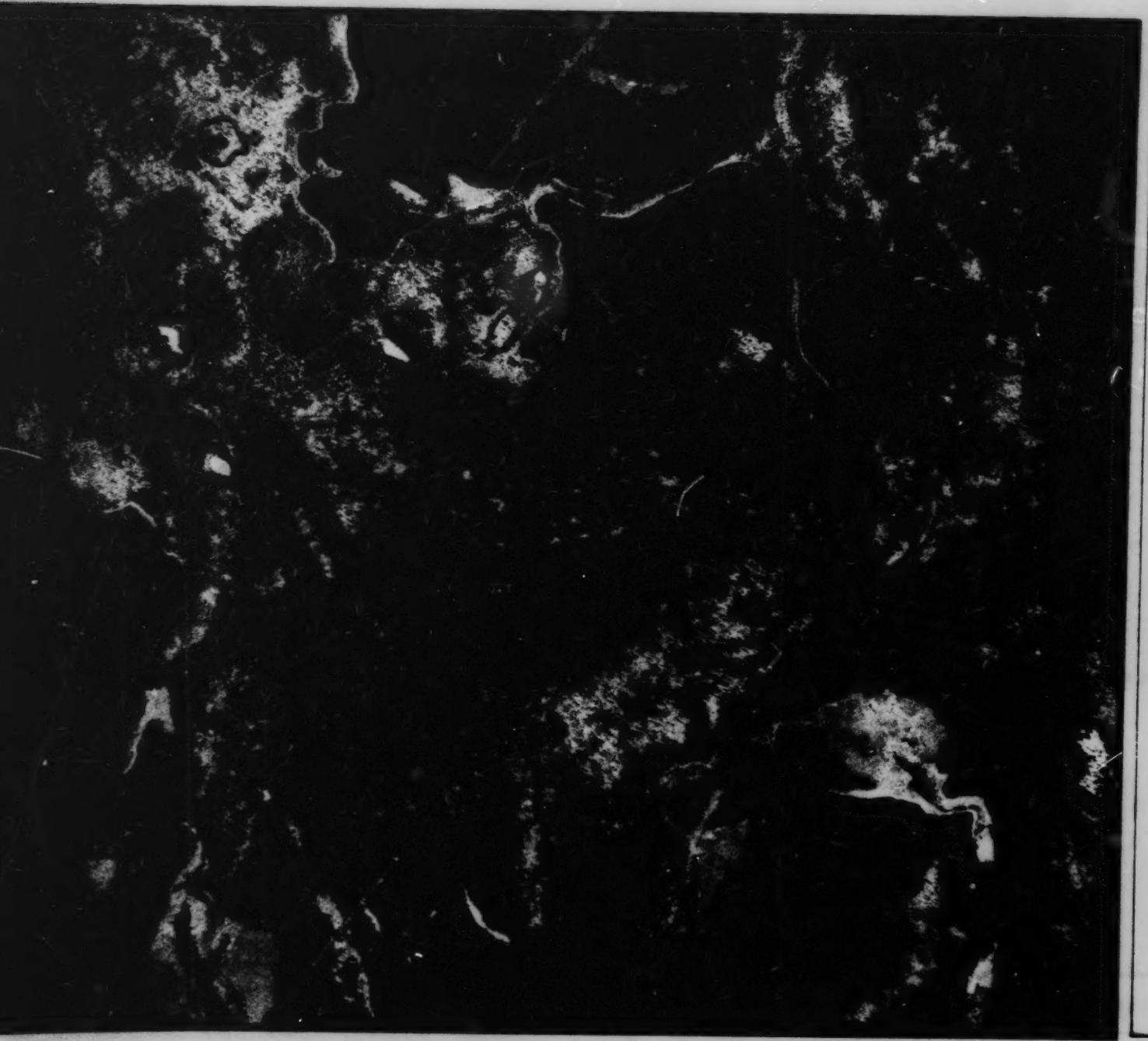


FIGURE 2a

GEOLOGICAL INTERPRETATION

BENDING LAKE ROAD

(WP 18-77-03, CHAINAGE 344+00)

SCALE 1:15840
DATE OF PHOTOGRAPHY: 1977

LEGEND

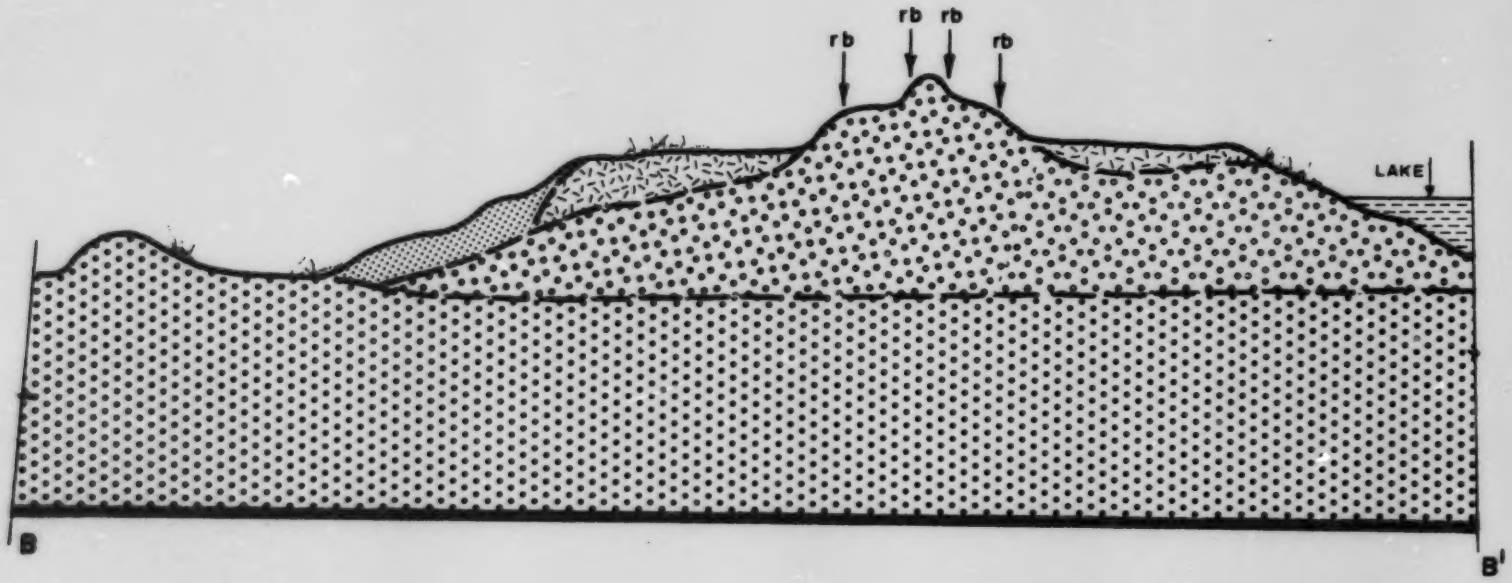
gl - GLACIOLACUSTRINE DEPOSITS
em - END MORAINE, WORKED BY WATER CURRENT
bd - BEACH DEPOSITS
od - OUTWASH DEPOSITS
gm - GROUND MORAINE
sb - SURFACE BOULDERS
- RAISED BEACH
- V SHAPED GULLY

N

FIGURE No. 2b CROSS-SECTION B-B'

NOT TO SCALE

(SEE FIGURE No 2a)



LEGEND

- END MORAINE
- BEACH DEPOSITS
- GROUND MORAINE
- GLACIO LACUSTRINE DEPOSITS
- rb RAISED BEACH

SPOOL A OT E - SEE LAF 40

DATE OF PHOTOGRAPH 1971
SCALE 1: 10000

FIGURE No. 20 - GEOLOGICAL INTERPRETATION
(Ab 10-TT-04, CHAINAGE 11 + 000)
BENDING LAKE ROAD

BENDING LAKE ROAD
ALIGNMENT
APPROXIMATE
(MOVED IN)
dq
dq
dq

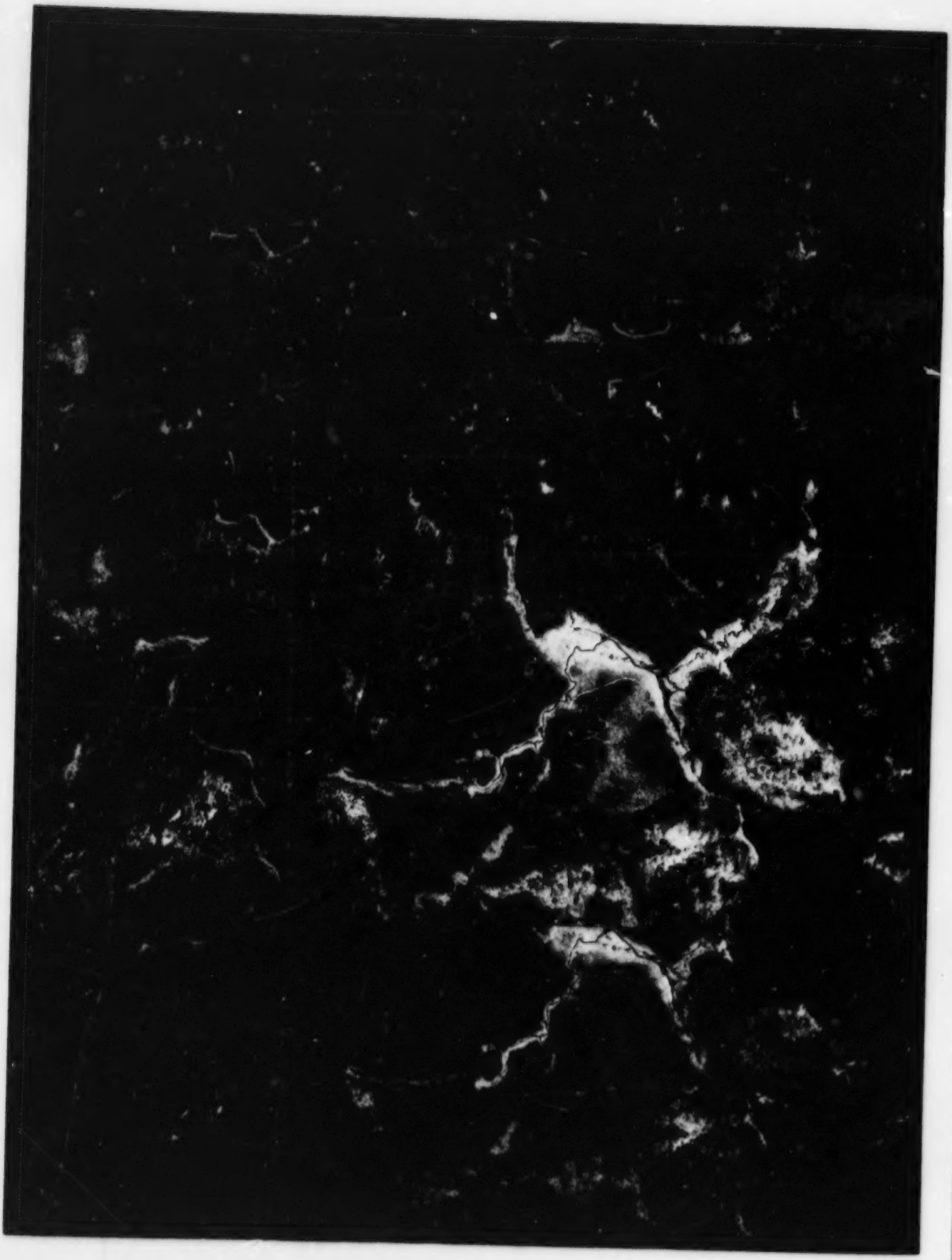
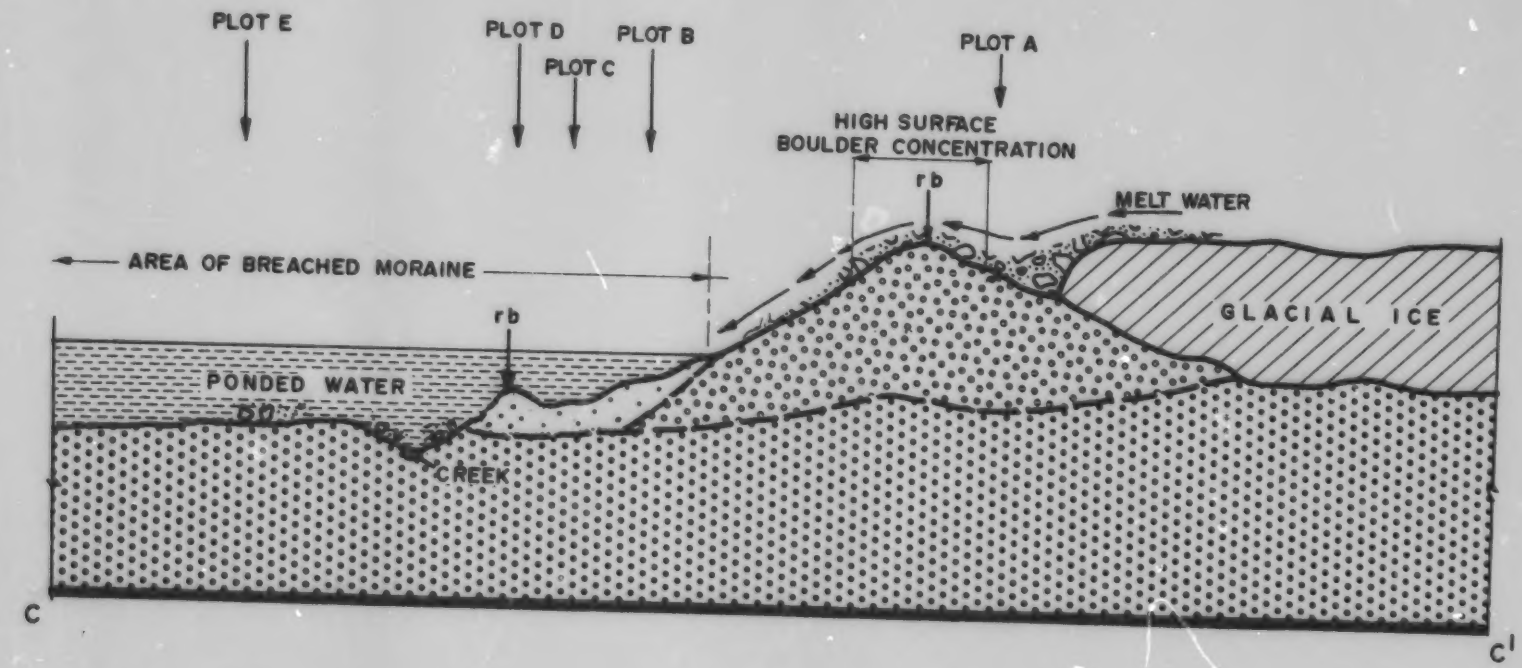


FIGURE No. 3b CROSS-SECTION C-C'

NOT TO SCALE

(SEE FIGURE No. 3a)



LEGEND

- END MORAINE
- OUTWASH DEPOSITS
- GROUND MORAINE
- BOULDERS
- rb RAISED BEACH

PLOTS A TO E – SEE PAGE 22-24 FOR EXPLANATIONS.

APPENDIX C

GROUND PHOTOGRAPHS

Photo No. 1
Portion of road cut prepared for analysis. Note percentage of medium size boulders and large surface boulder at top of cut.

Photo No. 2
Probing with Pionjar Drill in attempt to estimate boulder concentrations. Note piles of large boulders removed from the road cut (both sides of photo).

Photo No. 3
Material typical of Hwy. 631 area; note concentration of small to medium size boulders. Landforms poorly developed and interrupted by bedrock outcrops, as visible in the background of this photo.

Photo No. 4
Note shallow, heavily revegetated road cuts typical of large portions of Hwy. 631.

Photo No. 5
Road cut through a section of the shallow till typical of this area. Note the high percentage of large boulders.

Photo No. 6
Extremely high surface boulder concentration resulting from water reworking of the till and removal of finer material.

APPENDIX D

REFERENCES

Bird and Hale Ltd., 1977. Surveillance of the environmental effects of a highway facility by remote sensing. A state-of-the-art. Ontario Ministry of Transportation and Communications, Ref. RR209. 75 p.

Bird and Hale Ltd., 1978. Granular materials assessment, Pine Point Highway - Hay River, N.W.T.. Indian and Northern Affairs, Canada. 208 p.

Bird and Hale Ltd., 1977-1981. Granular materials searches for the Ontario Ministry of Transportation and Communications: south of Wawa; Highway 17-Blind River; Highway 144-Gogama; Highway 596-Kenora; Bending Lake Road; and, Detour Lake Road areas.

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Colwell, Robert N. (editor in chief), 1983. Manual of remote sensing. second edition. American Society of Photogrammetry. 2440 p. in two volumes.

Mollard, D.G. and J.D. Mollard, 1980. Marmion Lake Area (NTS 528/NW), District of Rainy River. Northern Ontario engineering geology terrain study 55. Ontario Geological Survey, Ontario Ministry of Natural Resources. 28 p. accompanied by Maps 5073 and 5104, scale 1:100,000.

Ontario Department of Lands and Forests, 1965. "Surficial geology map S165". scale 1:506,880.